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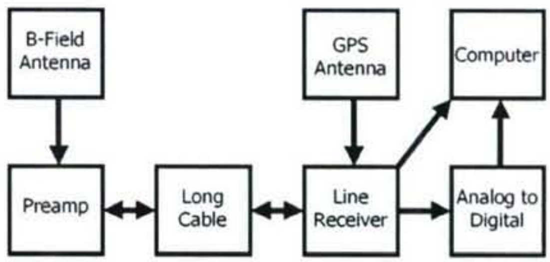
The Air Force Grant documented here directly resulted in the purchase of hardware eight VLF receivers. Five of these receivers have been deployed successfully and are operating regularly and reliably. The remaining are pending imminent deployment. The new receiver sites have enabled Stanford to jumpstart a fully-funded THY program, with funds from Stanford University and NASA, which will enable a great expansion of this network, and in addition, provides a new dataset which will greatly support Stanford's scientific studies of VLF and magnetospheric and ionospheric physics.

I. Introduction

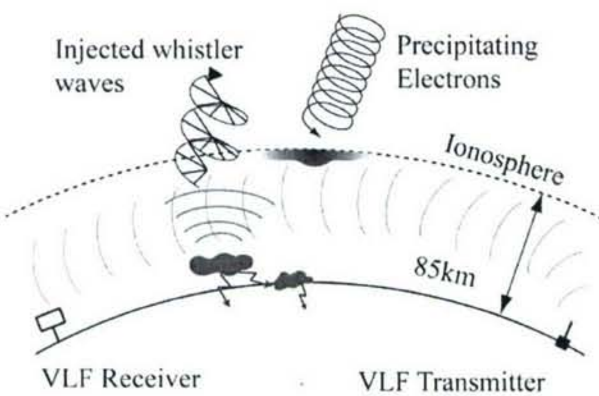
Air Force grant FA9550-06-1-0519 awarded funds in the amount of $26,400 to Stanford University in support of hardware costs for the construction of VLF receivers to be deployed worldwide. The receiver costs are in direct support of Stanford's effort to place ground-based VLF receivers for educational outreach, as part of the International Heliophysical Year (IHY),and the United Nations Basic Space Science Initiative, which together seek to create and expand networks of science instruments to developing nations. In addition to the outreach element, however, it is also expected that the data gathered from these new receiver sites will directly support Stanford's ongoing research, in conjunction with other Air Force grants, on VLF remote sensing of >100 keV radiation belt electron precipitation onto the ionosphere.

II. Stanford ELF/VLF Receivers and applications

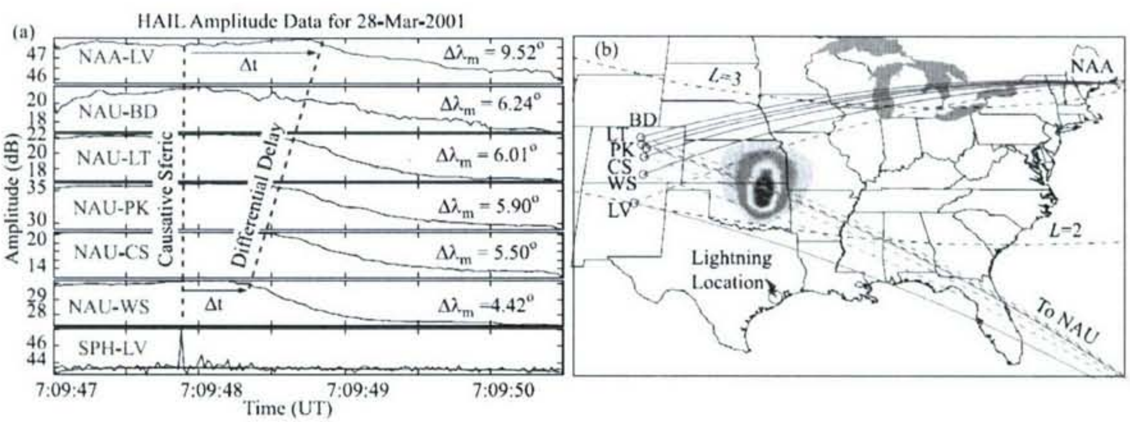
In recent years, Stanford has completed a new version of its VLF receiver, which combines the excellent sensitivity to small signals, with new advances in GPS timing, digitization and real-time software, and circuit board fabrication, to produce the



Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education (AWESOME). The AWESOME has now been deployed in ~40 locations worldwide, many in support of the Air Force's TIPER program, as well AFRL/NRL's HAARP facility in Gakona, Alaska. The AWESOME receiver is capable detecting nearly any signal above the atmospheric noise, including lightning-generated radio atmospherics and whistlers, along with magnetospheric chorus and hiss. The cost of the AWESOME receiver, including parts, labor, and shipping, has been estimated at $3300.



A simpler application of VLF receivers, however, involve detecting the amplitude and phases of individual frequencies corresponding to VLF transmitters, operated by US and other navies worldwide for long range communications. In addition, however, these VLF transmitter signals can also act as an electromegnetic probe for remote sensing for the lower ionosphere (80 km), which is ordinarily difficult to study because it is too high for balloons, yet too low for satellite orbit. For instance, it is a well known fact that lightning releases substantial energy at VLF frequencies into the Earth-ionosphere waveguide. Some of this energy couples through the ionosphere into the magnetosphere, where it can interact with trapped radiation belt particles, pitch-angle scatter them, and thereby cause them to precipitate onto the ionosphere. VLF signals propagating in the Earth-ionosphere waveguide can remotely sense this ionospheric disturbance, known as lightning-induced electron precipitation (LEP), because conditions of the wave's propagation have changed. Arrays of VLF receivers, like the HAIL array in Western USA, have been able to determine the geographic shape of these disturbances. However, a more full worldwide approach is needed to answer a critical scientific question: what role does LEP play in the losses of >100 keV radiation belt particles?



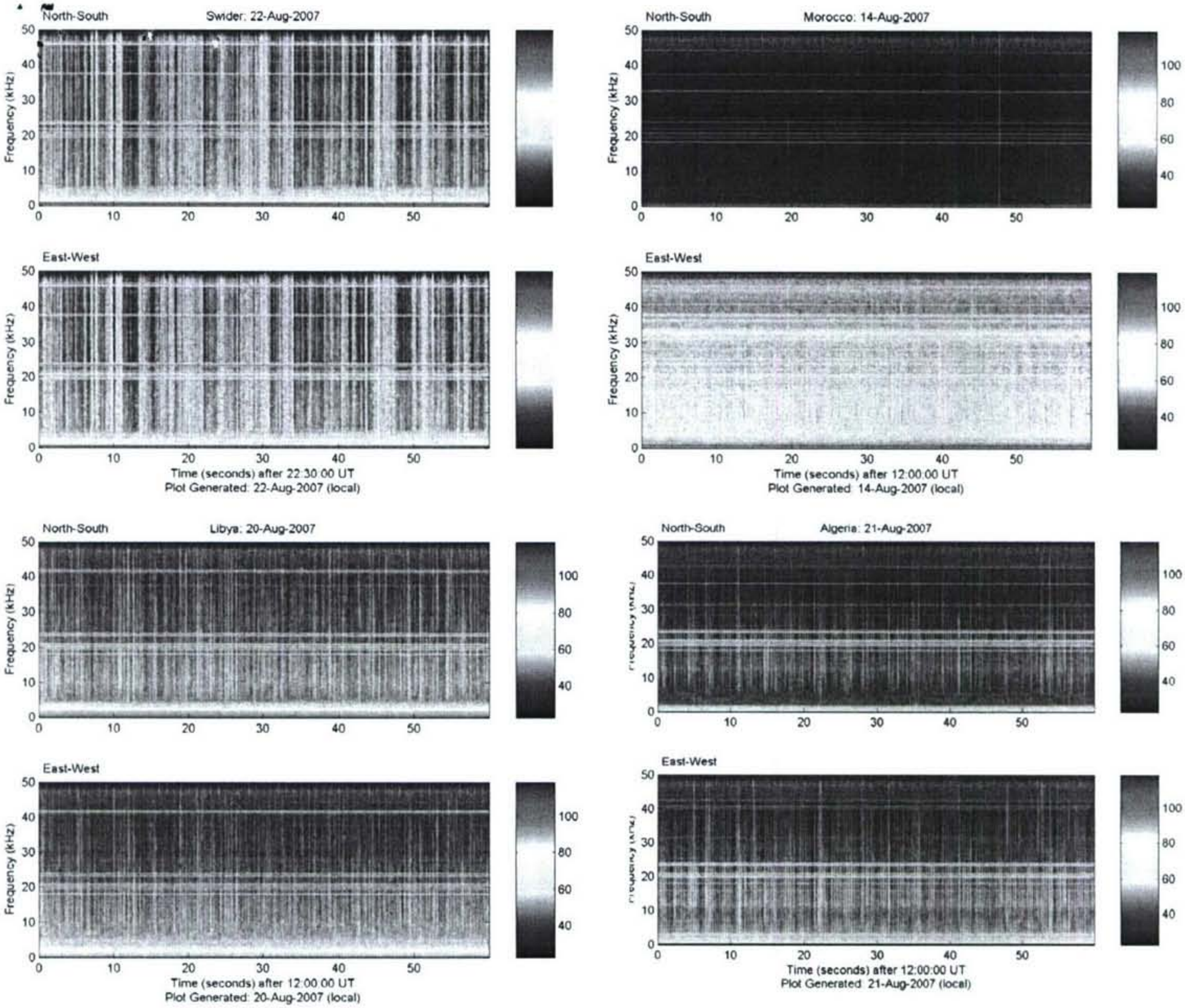
III. The International Heliophysical Year

Separate from these scientific goals, is the effort currently underway by the United Nations Basic Space Science Initiative (UNBSSI), with NASA participating heavily, to utilize the International Heliophysical Year (2007-09) as an opportunity to foster arrays of science instruments in developing nations in order to bolster the scientific presence there. Stanford has been chosen as a key participant in this effort, with the AWESOME receiver, due to a combination of AWESOMEs extremely broad scientific applications, low-cost (without any loss of sensitivity), and its ease of use. The goals of the IHY are therefore synergistic with Stanford's efforts to set up new arrays of VLF receivers in other regions. However, in order to properly leverage this opportunity, Stanford needed to demonstrate that the deployment and operation of VLF receivers could be achieved in this matter, with reliable and usable data obtained.

IV. Results

The $26,4000 grant covered the hardware costs of 8 VLF receivers, but did not cover any costs of personnel required to locate site hosts, or communicate with site hosts for the setup of the receiver. These costs fell under other grants. In Summer and Fall 2006, parts were acquired and systems build, including circuit boards, GPS units, boxes and specialized cables, transformers, antenna loops, ADC cards, and other required materials.

As a result of this grant, VLF receivers have already been set up in Algiers (Algeria), Rabat (Morocco), Sebha (Libya), Akure (Nigeria), Swider (Poland), and other receivers have already been built in preparation for deployment to Alexandria (Egypt), Suva (Fiji), and Uzbekistan. The Algiers and Rabat receivers were set up in July 2006 by Umran Inan, and the Libya trip followed in June 2007. The Swider receiver was set up by Marek Golkowski in January 2007. Below are sample spectrograms from Algeria, Morocco, Libya, and Poland. The Nigeria site has been set up successfully and run briefly, but is awaiting the end of a long power outage before resuming regular operations.



V. Conclusions

The Air Force Grant documented here directly resulted in the purchase of hardware eight VLF receivers. Five of these receivers have been deployed successfully and are operating regularly and reliably. The remaining are pending imminent deployment. The new receiver sites have enabled Stanford to jumpstart a fully-funded IHY program, with funds from Stanford University and NASA, which will enable a great expansion of this network, and in addition, provides a new dataset which will greatly support Stanford's scientific studies of VLF and magnetospheric and ionospheric physics.